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OF FLIGHT SCIENCES

Final Report

PROGRAM OF RESEARCH IN STRUCTURES AND DYNAMICS

NGR 09-010-078

with
The George Washington University
and
NASA Langley Research Center

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FOREWORD

This is the final technical report prepared under NASA Grant NGR 09-010-078. It summarizes the educational and research work done by the faculty and staff supported by this grant during the period 1972-1987. Detailed description of the research work is given in the publications listed in Appendices I and II.

Program of Research in
STRUCTURES AND DYNAMICS
NGR 09-010-078

FINAL REPORT
February 1972-December 1987

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Final Report
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ABSTRACT

The Structures and Dynamics Program was first initiated in 1972 with the following two major objectives:

a) to provide a basic understanding and working knowledge of some key areas pertinent to structures, solid mechanics, and dynamics technology including computer aided design; and

b) to provide a comprehensive educational and research program at the NASA Langley Research Center leading to advanced degrees in the structures and dynamics areas.

During the operation of the program the research work was done in support of the activities of both the Structures and Dynamics Division and the Loads and Aeroelasticity Division at NASA Langley Research Center. The Structures and Dynamic Program was an integral part of the Joint Institute for Advancement of Flight Sciences' major research projects, which are affiliated with the Department of Civil, Mechanical and Environmental Engineering of George Washington University.

During the period 1972 to 1986 the Program provided support for two full-time faculty members, one part-time faculty member, three postdoctoral fellows, one research engineer, eight programmers, and 28 Graduate Research Assistants. The faculty and staff of the program have published 144 papers and reports, and made 70 presentations at national and international meetings, describing their research findings. In addition, they organized and helped in the organization of 10 workshops and national symposia in the structures and dynamics areas. The Graduate Research Assistants and the students enrolled in the Program have written 20 M.S. theses and 2 D.Sc. dissertations.

I. SUMMARY OF OVERALL PROGRESS

The Structures and Dynamics Program was first initiated in February 1972 with the following two major objectives:

a) to provide a basic understanding and working knowledge of some key areas pertinent to structures, solid mechanics, and dynamics technology including computer aided design; and

b) to provide a comprehensive educational and research program at the NASA Langley Research Center leading to advanced degrees in the structures and dynamics areas.

In the first two years of its operation the Program focused on computer-aided structural design, and the research was conducted in support of the Design Technology Branch of the Structures and Dynamics Division. In succeeding years the Program was broadened to encompass some of the research activities within other branches of the Structures and Dynamics Division. In the last year of the program (1987) the research was focused on tire modeling and analysis.

The four NASA technical monitors for the Program were:

Robert E. Fulton (February 1972-December 1973)

Roger A. Anderson (January 1974-December 1980)

Harvey G. McComb, Jr. (January 1981-December 1986)

Martha Robinson (January 1987-December 1987)

During the period February 1972-December 1987, the Program provided support for two full-time faculty members, one part-time faculty member, three postdoctoral fellows, one research engineer, eight programmers, and 28 Graduate Research Assistants.

The faculty and staff of the Program have published 144 papers (these include 31 NASA reports, 77 archival journal articles, 54 papers in conference proceedings, and 5 contributions to books). They have edited 8 books, made 70 presentations at national and international meetings, and organized 10 workshops and symposia in the structures and dynamics areas. The Graduate Research Assistants and students enrolled in the program have written 20 M.S. theses and 2 D.Sc. dissertations. A list of the publications, presentations, theses and dissertations, workshops and symposia are given in Appendices I, II and III. The faculty and staff supported by the Program are listed subsequently, and the Graduate Research Assistants are listed in Appendix IV.

Faculty and Staff

Dean Harold Liebowitz, Principal Investigator (1972-1987)

Ahmed K. Noor, Technical Director and Professor of Engineering and Applied Science

(April 1972-Dec. 1987)

Richard S. Brice, Associate Research Professor (July 1974-Aug. 31, 1978)

Harry L. Runyan, Associate Research Professor (part-time, April 1975-June 30, 1977)

Hussein A. Kamel, Postdoctoral Fellow (Summer 1974)

Kenneth Sidwell, Postdoctoral Fellow (Nov. 1, 1975-Sept. 7, 1977)

K. R. V. Kaza, Postdoctoral Fellow (May 1, 1976-Jan. 31, 1977)

John T. Dorsey, Visiting Engineer (July 1, 1981-June 25, 1982)

Pamela L. Rarig, Junior Programmer (July 1972-August 1974)

Stephen Hartley, Programmer (March 30, 1975-Aug., 17, 1977)

Mary O. Smith, Junior Programmer (July 7, 1975-Feb. 20, 1977)

Jeanne M. Peters, Programmer (Oct. 3, 1977-Dec. 1987)

Gregg Strohkorb, Programmer (June 4, 1979-Sept. 3, 1982)

Macon A. Shibut, Programmer (July 1, 1980-Feb. 21, 1983)

Ted C. Michorczyk, Research Engineer (July 25, 1983-July 31, 1984)

Sandra L. Whitworth, Programmer (June 3, 1985-July 31, 1987)

Mary Torian, Secretary (April 1, 1977-Dec. 1987)

II. EDUCATIONAL PROGRAM

The curriculum in the Structures and Dynamics Program was designed to provide the students with both fundamental and specialized knowledge of some key areas pertinent to structures, solid mechanics and dynamics technology, including advanced computer applications in interdisciplinary and optimum design of aircraft, aerospace and other structures.

In support of this curriculum thirty courses were offered at NASA Langley. These consisted of 6 applied science (mathematics) courses, 10 engineering science courses, 3 civil engineering courses, 8 computer science courses, and 3 mechanical engineering courses. The courses are listed subsequently and a complete description of these courses is given in the SEAS catalog.

ApSc-211 Analytical Methods in Engineering I
ApSc-212 Analytical Methods in Engineering II
ApSc-213 Analytical Methods in Engineering III
ApSc-214 Analytical Methods in Engineering IV
ApSc-215 Analytical Methods in Engineering V

ApSc-216	Analytical Methods in Engineering VI
CE-254	Special Topics in Engineering Analysis
CE-261	Analysis of Plates and Shells
CE-263	Theory of Structural Stability
CS-159	Programming and Data Structures
CS-202	Introduction to Computer Systems II
CS-203	Microprocessors and Microcomputers
CS-214	Data Structures
CS-215	Advances in Data Structures and High Level Algorithms
CS-227	Management Information Systems and Database Management
CS-285	Approximation of Functions and Data Representations
EngS-221	Theory of Elasticity I
EngS-234	Composite Materials
EngS-281	Advanced Programming Techniques for Engineering Mechanics Problems
EngS-283	Application of Computer Graphics in Engineering
EngS-284	Numerical Methods in Engineering
EngS-285	Finite Element Methods in Engineering Mechanics
EngS-286	Analysis and Design of Thin-Walled Structures
EngS-288	Advanced Finite Element Methods in Structural Mechanics
EngS-289	Special Topics in Theoretical and Applied Mechanics - Optimization of Engineering Systems
EngS-314	Advanced Numerical Methods in Engineering
ME-215	Theory of Vibrations
ME-221	Intermediate Fluid Mechanics
ME-223	Aeroelasticity

III. RESEARCH PROJECTS

A detailed description of the research activities of the faculty and staff are described in the annual reports. Reviews of these activities were made each year to the senior personnel of the Structures and Dynamics Division. Also, reviews of the activities of the Graduate Research Assistants were made during the Annual Student Workshops in the summers of 1983, 1984, 1985 and 1986. Herein, a brief description is given of the thirteen research projects covered under the grant.

1. Solution Strategies for Structural Problems on New Computing Systems

This research was initiated in 1975. The objective of the research was to study the impact of major hardware and software features of new computing systems on solution strategies of structural problems. The computing systems considered included CDC STAR 100, CYBER 203,

CYBER 205, PRIME 750 minicomputer, and the FPS-120B array processor. Research-oriented pilot finite element programs, which exploited the major features of these machines, have been developed. The programs were used to investigate the efficiency of various numerical procedures on vector computers and attached processors. The research helped in forming guidelines for the design of large-scale structural analysis programs in a distributed computing environment where the independent calculations are performed on different machines (e.g., vector computers, minicomputers, attached processors, and projected new hardware configurations).

2. Improved Numerical Procedures for Nonlinear Problems

This research was conducted during the period 1979-1986. The overall objective of this research was to develop effective discretization techniques and computational strategies for the solution of large-scale nonlinear structural and thermal problems. Both static (steady state) and dynamic (transient) problems were considered. Work on this project included the development of:

a) accurate and efficient multifield (mixed) finite element models for the free vibration and nonlinear analyses of composite shells;

b) simple and efficient penalty finite element models for the large-rotation static and dynamic analysis of structures;

c) hybrid Bubnov-Galerkin/perturbation techniques for the solution of nonlinear structural and thermal problems; and

d) reduction methods for substantially reducing the computational effort required in the solution of nonlinear structural and thermal problems.

The mixed models developed were based on using independent shape functions for both the stress resultants and the generalized displacements and allowing the stress resultants to be discontinuous at interelement boundaries. The effectiveness of the penalty models developed was demonstrated by means of numerical examples of static, postbuckling and dynamic elastica problems. The hybrid analytical technique was found to combine the best elements of the regular perturbation method and the Bubnov-Galerkin technique and at the same time it overcomes their major drawbacks. The reduction methods developed were a hybrid combination of the finite element, Rayleigh-Ritz and perturbation techniques. The application of these methods resulted in

substantially reducing the computational effort in solving large-scale nonlinear problems. The scope of the work on reduction methods included moderate and large rotation nonlinear problems of framed structures, composite shells and thermal problems. In the structural problems both conservative as well as nonconservative loadings were considered, and in the thermal problems, both nonlinear conduction, convection, and radiation were considered. Also, problems with nonconservative loadings were considered.

3. Postbuckling and Failure Analysis of Composite Panels

The objective of this research was to study the postbuckling response and failure characteristics of flat and curved laminated composite panels subjected to compressive, shear and combining loadings. Work on this project included the application of reduction methods to the determination of the bifurcation buckling loads, as well as to tracing the post-bifurcation and post-limit point paths. Also, a simple criterion was developed for predicting initiation of delamination in composite panels in the postbuckling range. The criterion is based on the magnitude of the transverse shear strain density. Experiments have shown that delamination starts at the locations of maximum transverse shear strain energy density.

4. Analysis and Modeling of Aircraft Tires

This research was conducted during the period 1980-1987. The overall objective of this research was to develop accurate and cost-effective strategies for predicting the tire response under normal operating conditions. The different activities of this project included:

a) Development of various shear-flexible toroidal-shell finite element models for predicting the nonlinear response of tires subjected to inflation pressure as well as mechanical loadings. The finite element models developed included both displacement as well as mixed models, with independent shape functions for the stress-resultants and generalized displacements. Also, semi-analytic finite element models were developed in which the tire variables were represented by Fourier series in the circumferential direction, and piecewise polynomials in the meridional direction.

b) Application of single- and multiple-parameter reduction methods to the nonlinear analysis of tires. These methods allow a substantial reduction in the original number of degrees of freedom to be made, and proved to be very effective for both moderate rotation and large

rotation problems; and

c) Identification of the basic types of symmetry (and their combinations) exhibited by the tire response, and development of simple computational strategies for exploiting these symmetries in the finite element analysis. Also, techniques were developed for reducing both the size of the discrete model and the cost of analysis of tires in the presence of symmetry-breaking conditions (e.g., unsymmetry of the tire material, geometry, and/or loading).

5. Modeling and Analysis of Large Space Structures

This research was conducted during the period 1976-1986. The overall objective of the research was to develop effective modeling and analysis techniques for large space structures such as space solar power stations, large space mirrors, antennas, power systems for supporting space operations, and the space station. The activities in this project included development of a) new concepts for deployable space truss structures with applications to large space antennas where the shape can be changed depending on the mission, and the advanced remote manipulator system used; and b) rational continuum models to simulate the response of lattice structures with pin as well as rigid joints. Also, the effects of joint flexibilities have been studied. The models developed were applied to thermal elastic stress, vibration and stability analyses of large lattice structures, including the candidate configuration for the space station.

6. Effective Computational Strategies for Large-Scale Structural Problems

The objective of this research was to develop innovative solution methodologies and effective computational strategies for solving large-scale structural problems. A computational strategy was developed for generating the response of a complex structural system using large perturbations from the response of a simpler system. The two key elements of the strategy are:

a) operator splitting or restructuring of the governing equations of the complex structural system to delineate the contributions of the simpler system:

b) application of preconditioned conjugate gradient (PCG) technique to generate the response of the original complex system. The preconditioning matrix is selected to be the matrix of the simpler system. The similarities between the proposed strategy and that based on reduction methods have been identified and exploited to provide a physical meaning for the preconditioned residual vectors used in the PCG technique. The effectiveness of the proposed strategy

has been demonstrated by means of a number of examples including:

a) buckling and vibration analysis of anisotropic panels and anisotropic shells of revolution (with particular emphasis on tires), and

b) linear and nonlinear static analysis of symmetric structures with unsymmetric boundary conditions.

In each case the proposed strategy, in addition to giving highly accurate approximations to the response of the original system, provided sensitivity information concerning the effect of the complicated factors on the response of the system .

7. Quality Assessment and Control of Finite Element Solutions

The work in this project focused on developing error indicators as part of a simple computational procedure for improving the accuracy of finite element solutions for plate and shell problems. The procedure is based on using an initial (coarse) grid and a refined (enriched) grid, and approximating the solution for the refined grid by a linear combination of a few global approximation vectors (or modes) which are generated by solving two uncoupled sets of equations in the coarse grid unknowns and the additional degrees of freedom of the refined grid. The global approximation vectors provide quantitative pointwise information about the sensitivity of the different response quantities to the approximation used, and therefore, serve as error indicators.

8. Design-Oriented Approximate Methods of Analysis

This research was performed during the period 1972-1974. The goal of the research was to develop efficient algorithms which are tailored especially for repetitive analysis and gradient computation required in the automated (optimum) design of large structural systems. The techniques developed were a hybrid combination of a) the Taylor series expansion of the response quantities with respect to the design variables, and the reduced basis technique, and b) Taylor-series expansion of the response quantities and iterative techniques. For very large structures the hybrid techniques were applied in conjunction with substructuring techniques.

9. Structures Modules in Large Engineering Design Software Systems

This research was conducted during the period 1975-1978 in support of the NASA IPAD Project. The objective of this research was to define the methodology and capabilities for

self-contained structures modules and submodules, and their interface with other modules in large engineering design software systems. The different activities of this project included:

a) development of a set of software tools for use in the design of database management systems which combine portability, simplicity and standardization,

b) development of mathematical models for the interaction of virtual memory managers and virtual I/O buffer managers,

c) definition of operating system primitive commands to promote cooperation between the operating system components and the database management programs.

10. Impact Dynamics and Crashworthiness of Aircraft Structures

This research was directed towards effective ways of modeling the post-impact response of large complex structures and the evaluation of crashworthiness of aircraft structures. The different activities of this project included:

a) developing mixed finite element models for the large-rotation dynamic analysis of axisymmetric shells, spatial beams with arbitrary curvatures, and beams made of composite materials; and

b) assessing the applicability and range of validity of reduction methods as applied to the nonlinear dynamic analysis of spatial beams.

11. Effect of Dynamic Characteristics of Aircraft on the Fatigue-Life Design

This research was performed during the period 1972-1975. The objective of the work was to establish a relationship between the structure static strength, dynamic characteristics, and its fatigue life. Structures of the wing box types were considered, and the loads ranged from a harmonic excitation to a simplified model of a random gust load in a turbulent atmosphere. The problem was investigated by computing the fatigue life using each of the following three methods:

a) static method in which the excitation force was treated as a pseudo-static one and its cycles were assumed to act independently of each other,

b) a static method as the one in a) above but with cycles combined according to the input real time load history, and

c) dynamic method in which the real time load input was used to generate stress history

accounting for the dynamic amplification factors for all the eigenmodes. In each of the three methods, standard equations describing the material fatigue properties and cumulative damage laws were used. The results obtained by the three methods were compared for different load amplitudes and structure nature frequencies. This study provided some insight into when to replace the computationally expensive dynamic analysis by the less expensive psuedo-static analysis, as well as the range of validity of the latter as a function of load amplitudes and natural frequencies.

12. Rotor Dynamics

This research was conducted during the years 1976-1977. The work involved development of mathematical models for analyzing the aeroelastic stability of rotorcraft. An efficient approach was developed for deriving the nonlinear flap-lag-axial equations of motion of rotating beams. The equations were solved using an integrating matrix method and the bands of instability were identified.

13. Flutter and Unsteady Loads

This research was conducted during the years 1975-1977. This work included the development and verification of analytical and numerical methods for predicting air load distributions on oscillating or impulsively moving lifting surfaces and wing-body combinations. In particular, the work included the development of a method for analyzing the nonlinear effects in aircraft response to atmospheric turbulence. The method combined the techniques for the analysis of the response of nonlinear dynamic system to random process and the formulation of an amplitude modulated random process which is used as a model for atmospheric turbulence. Also, an exact analysis was made for the response of linear dynamic systems to the product of two independent Gaussian processes, which include an amplitude modulated process as a special case.

IV. EQUIPMENT

The list of equipment purchased for the faculty and staff of the Structures and Dynamics Program is given in Appendix V. Of the total of \$32,331.59, \$20,000 was charged to the grant and the balance was covered by the School of Engineering and Applied Science fund. In 1987 the ownership of the equipment was transferred to NASA Langley.

APPENDIX I - LIST OF PUBLICATIONS AND PRESENTATIONS

Publications

1. Noor, A. K., "Improved Mixed Finite Difference Scheme for Thermoelastic Stress Analysis of Noncircular Cylindrical Shell Roofs," Proceedings of the IASS Conference on Shell Structures and Climatic Conditions, Calgary, Canada, July 3-6, 1972, pp. 335-345.
2. Noor, A. K. and Stephens, W. B., "Mixed Finite Difference Scheme for Free Vibration Analysis of Noncircular Cylinders," TN-D-7107, Feb. 1973.
3. Noor, A. K., "Noncircular Cylinder Vibration by Multilocal Method," Journal of the Engineering Mechanics Division, ASCE, Vol. 99, No. EM2, April 1973, pp. 389-407.
4. Andersen, C. M. and Noor, A. K., "Use of Symbolic Manipulation in the Development of Two-Dimensional Finite Elements," SIAM National Meeting, Hampton, VA, June 18-21, 1973.
5. Noor, A. K., "Nonlinear Analysis of Space Trusses," Journal of the Structural Division, ASCE, Vol. 100, No. ST3, March 1974, pp. 533-546.
6. Noor, A. K., "Free Vibration of Multilayered Composite Plates," AIAA Journal, Vol. 11, No. 7, July 1973, pp. 1038-1039.
7. Noor, A. K. and Schnobrich, W. C., "On Improved Finite-Difference Discretization Procedures," in Variational Methods in Engineering, ed. by Brebbia and Tottenham, Southampton University Press, Vol. II, 1972, pp. 12/1-12/50.
8. Noor, A. K., "Mixed Finite-Difference Scheme for a Class of Linear and Nonlinear Structural Mechanics Problems," in Developments in Mechanics, Vol. 7, Proceedings of the 13th Midwestern Mechanics Conference, Pittsburgh, PA, Aug. 1973, pp. 657-674.
9. Noor, A. K., "Mixed Method for the Nonlinear Analysis of Pin-Jointed Trusses," Proceedings of the Fourth Australasian Mechanics Conference, Brisbane, Australia, Aug. 20-22, 1973, pp. 217-224.
10. Noor, A. K., "Mixed Finite-Difference Scheme for Analysis of Simply Supported Thick Plates," Computers and Structures, Vol. 3, No. 5, Sept. 1973, pp. 967-982.
11. Noor, A. K., Stephens, W. B. and Fulton, R. E., "An Improved Numerical Process for the Solution of Solid Mechanics Problems," Computers and Structures, Vol. 3, No. 6, Nov. 1973, pp. 1397-1437.
12. Noor, A. K. and Stephens, W. B., "Comparison of Finite-Difference Schemes for Analysis of Shells of Revolution," NASA TN-D-7337, Dec. 1973.
13. Noor, A. K. and Lowder, H. E., "Approximate Techniques of Structural Reanalysis," Computers and Structures, Vol. 4, No. 4, 1974, pp. 801-812.
14. Noor, A. K. and Rarig, P. L., "Three-Dimensional Solutions of Laminated Cylinders," Computer Methods in Applied Mechanics and Engineering, Vol. 3, No. 3, May 1974, pp. 319-334.
15. Andersen, C. M. and Noor, A. K., "Use of Goup-Theoretic Methods in the Development of Nonlinear Shell Finite Elements," Proceedings of the International Conference on Symmetry, Similarity and Group-Theoretic Methods in Mechanics, Calgary, Canada, 1974, pp. 533-558.
16. Noor, A. K. and Fulton, R. E., "Impact of CDC-STAR-100 Computer on Finite Element

Systems," Proceedings of the Sixth ASCE Conference on Electronic Computation, Atlanta, GA, Aug. 1974, pp. 166-202; also Journal of the Structural Division, ASCE, Vol. 101, No. ST4, April 1975, pp. 731-750.

17. Noor, A. K. and Mathers, M. D., "Nonlinear Finite Element Analysis of Laminated Composite Shells," Proceedings of the International Conference on Computational Methods in Nonlinear Mechanics, Austin, TX, Sept. 1974, pp. 999-1009.
18. Noor, A. K., "Multiple Configuration Analysis Via Mixed Method," Journal of the Structural Division, ASCE, Vol. 100, No. ST9, Sept. 1974, pp. 1991-1997.
19. Noor, A. K., "Stability of Multilayered Composite Plates," Fibre Science and Technology, Vol. 8, April 1975, pp. 81-89.
20. Noor, A. K. and Lowder, H. E., "Structural Reanalysis Via a Mixed Method," Computers and Structures, Vol. 5, No. 1, April 1975, p. 9-12.
21. Noor, A. K. and Mathers, M. D., "Shear-Flexible Finite Element Models of Laminated Composite Plates and Shells," NASA TN-D-8044, Dec. 1975.
22. Noor, A. K. and Voigt, S. J., "Hypermatrix Scheme for Finite Element System on CDC-STAR-100 Computer," Computers and Structures, Vol. 5, No. 5/6, Dec. 1975, pp. 287-296.
23. Noor, A. K. and Rarig, P. L., "Mixed Isoparametric Elements for Saint-Venant Torsion," in Developments in Mechanics, Vol. 8, Proceedings of the 14th Midwestern Mechanics Conference, University of Oklahoma, March 1975, pp. 171-192.
24. Noor, A. K. and Andersen, C. M., "Mixed Isoparametric Elements for Saint-Venant Torsion," (extended version of above paper), Computer Methods in Applied Mechanics and Engineering, Vol. 6, 1975, pp. 195-218.
25. Noor, A. K. and Lowder, H. E., "Approximate Reanalysis Technique with Substructuring," Journal of the Structural Division, ASCE, Vol. 101, No. ST8, Aug. 1975, pp. 1687-1698.
26. Noor, A. K. and Andersen, C. M., "Mixed Isoparametric Laminated Composite Plate and Shell Elements," Proceedings of the World Congress on Finite Element Methods in Structural Mechanics, Bournemouth, Dorset, England, Oct. 12-17, 1975.
27. Andersen, C. M. and Noor, A. K., "A Computerized Symbolic Integration Technique for Development of Triangular and Quadrilateral Composite Shallow-Shell Finite Elements," NASA TN-D-8067, Dec. 1975.
28. Brice, R. S. and Browne, J. C., "A Study of Feedback Coupled Allocation Policies in the Multiprocessor Computer Environment," Second Annual Sigmetrics Symposium on Measurement and Evaluation, Montreal, Canada, Sept. 20-Oct. 2, 1974.
29. Noor, A. K. and Mathers, M. D., "Anisotropy and Shear Deformation in Laminated Composite Plates," AIAA Journal, Vol. 14, No. 2, Feb. 1976, pp. 282-285.
30. Noor, A. K. and Mathers, M. D., "Finite Element Analysis of Anisotropic Plates," International Journal for Numerical Methods in Engineering, Vol. 11, 1977, pp. 289-307.
31. Noor, A. K. and Camin, R. A., "Symmetry Considerations for Anisotropic Shells," Computer Methods in Applied Mechanics and Engineering, Vol. 9, 1976, pp. 317-335.
32. Sherman, S. W. and Brice, R. S., "Performance of a Database Manager in a Virtual Memory System," SIGMOD International Conference on Management of Data, June 1976; Journal of Transactions on Database Systems, Dec. 1976.
33. Sherman, S. W. and Brice, R. S., "I/O Buffer Performance in a Virtual Memory System," Proceedings of Symposium on Simulation of Computer Systems, Boulder, CO, Aug. 1976.

34. Noor, A. K., "Symmetries in Laminated Composite Plates," Developments in Theoretical and Applied Mechanics, Vol. 8, Proceedings of the Eighth Southeastern Mechanics Conference, VPI&SU, Blacksburg, VA, April 1976, pp. 225-246.
35. Noor, A. K. and Hartley, S. J., "Nonlinear Shell Analysis Via Mixed Isoparametric Elements," Computers and Structures, Vol. 7, No. 5, Oct. 1977, pp. 615-626.
36. Noor, A. K., Kamel, H. A. and Fulton, R. E., "Substructuring Techniques - Status and Projections," Computers and Structures, Vol. 8, No. 5, May 1978, pp. 621-632.
37. Noor, A. K., Mathers, M. D. and Anderson, M. S., "Exploiting Symmetries for Efficient Postbuckling Analysis of Composite Plates," Proceedings of the 17th AIAA/ASME/SAE Structures, Structural Dynamics and Materials Conference, Valley Forge, PA, May 1976, pp. 39-55; also AIAA Journal, Vol. 15, No. 1, Jan. 1977, pp. 24-32.
38. Noor, A. K. and Andersen, C. M., "Mixed Isoparametric Finite Element Models of Laminated Composite Shells," (extended version of Ref. 26), Computer Methods in Applied Mechanics and Engineering, Vol. 11, 1977, pp. 255-280.
39. Andersen, C. M. and Noor, A. K., "Free Vibrations of Laminated Composite Elliptic Plates," NASA CP-2001, Advances in Engineering Sciences, Vol. 2, Nov. 1976, pp. 425-438.
40. Noor, A. K. and Hartley, S. J., "Effect of Shear Deformation and Anisotropy on the Nonlinear Response of Composite Plates," Chapter 4 in Developments in Composite Materials, ed. by G. Holister, Applied Science Publishers, Ltd., 1977, pp. 55-65.
41. Sidwell, K. W., "A Method for the Analysis of Nonlinearities in Aircraft Dynamic Response of Atmospheric Turbulence," NASA TN-D-8265, 1976.
42. Brice, R. S. and Sherman, S. W., "Empirical Comparison of Partitioned and Nonpartitioned buffer Management in Virtual Memory Systems," Proceedings of EUROCOMP, London, England, Sept. 1976.
43. Rhyne, R. H., Murrow, H. N. and Sidwell, K. W., "Atmospheric Turbulence Power Spectral Measurements to long Wavelengths for Several Meteorological Conditions," NASA SP-416, 1976, pp. 271-286.
44. Noor, A. K., Greene, W. H. and Anderson, M. S., "Continuum Models for Static and Dynamic Analysis of Repetitive Lattices," Proceedings of the 18th AIAA/ASME/SAE Structures, Structural Dynamics and Materials Conference, San Diego, CA, March 1977, pp. 299-310.
45. Noor, A. K., Greene, W. H. and Hartley, S. J., "Nonlinear Finite Element Analysis of Curved Beams," Computer Methods in Applied Mechanics and Engineering, Vol. 12, 1977, pp. 289-307.
46. Noor, A. K., "Thermoelastic Stress Analysis of Double-Layered Grids," Advances in Civil Engineering Through Engineering Mechanics (Proceedings of the meeting), May 1977, pp. 463-466.
47. Brice, R. S. and Sherman, S. W., "An Extension to the Performance of a Database Manager in a Virtual Memory System," Journal of Transactions on Database Systems, June 5, 1977.
48. Andersen, C. M. and Noor, A. K., "Symbolic Manipulation Techniques for Vibration Analysis of Laminated Elliptic Plates," NASA CP-2012, 1977, pp. 161-175.
49. Sidwell, K. W., "A Mathematical Study of a Random Process as an Atmospheric Turbulence Model," NASA CR-145200, May 1977.

50. Noor, A. K. and Hartley, S. J., "Evaluation of Element Stiffness Matrices on CDC-STAR-100 Computer," Computers and Structures, Vol. 9, No. 2, Aug. 1978, pp. 151-161.
51. Noor, A. K., "Thermal Stress Analysis of Double-Layered Grids," (extended version), Journal of the Structural Division, ASCE, Feb. 1978, Vol. 104, No. ST2, pp. 251-262.
52. Kvaternik, R. G. and Kaza, K. R. V., "Nonlinear Curvature Expressions for Combined Flapwise Bending, Torsion and Extension of Twisted Rotor Blades," NASA TM-X-73997, Dec. 1976.
53. Kaza, K. R. V. and Kvaternik, R. G., "Nonlinear Flap-Lag-Axial Equations of a Rotating Beam," AIAA Journal, Vol. 15, June 1977, pp. 871-874.
54. Kaza, K. R. V. and Kvaternik, R. G., "Nonlinear Aeroelastic Equations for Combined Flapwise Bending, Chordwise Bending, Torsion and Extension of Twisted Nonuniform Rotor Blades in Forward Flight," NASA TM-X-74059, Aug. 1977.
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Analysis," Seventh ASCE Conference on Electronic Computation, Washington University, St. Louis, MO, Aug. 6-8, 1979.

34. Sobieski, J. and Bhat, R. B., "Adaptable Structural Synthesis Using Advanced Analysis and Optimization Coupled by a Computer Operating System," 20th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, St. Louis, MO, April 4-6, 1979.
35. Noor, A. K., Peters, J. M. and Andersen, C. M., "Two-Stage Rayleigh-Ritz Technique for Nonlinear Analysis of Structures," Second International Symposium on Innovative Numerical Analysis in Applied Engineering Science, Montreal, Canada, June 16-20, 1980.
36. Reed, W. H., Foughner, J. T., Jr. and Runyan, H. L., Jr., "Decoupler Pylon - A Simple, Effective Wing/Store Flutter Suppressor," 20th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, St. Louis, MO, April 4-6, 1979.
37. Noor, A. K. and Peters, J. M., "Elastic Collapse Analysis of Shells Via Global-Local Approach," U.S.-Europe Workshop on Nonlinear Finite Element Analysis, Ruhr University, Bochum, West Germany, July 29-31, 1980.
38. Noor, A. K., "Recent Advances in Reduction Methods for Nonlinear Problems," Symposium on Computational Methods in Nonlinear Structural and Solid Mechanics, Washington, D.C., Oct. 6-8, 1980.
39. Noor, A. K. and Andersen, C. M., "Computerized Symbolic Manipulation in Nonlinear Finite Element Analysis," Symposium on Computational Methods in Nonlinear Structural and Solid Mechanics, Washington, D.C., Oct. 6-8, 1980.
40. Noor, A. K. and Peters, J. M., "Bifurcation and Postbuckling Analysis of Laminated Composite Plates Via Reduced Basis Technique," Joint ASME/ASCE Mechanics Conference, University of Colorado, Boulder, June 22-24, 1981.
41. Noor, A. K., "On Making Large Nonlinear Problems Small," Second International Conference on Finite Elements in Nonlinear Mechanics (FENOMECH '81), University of Stuttgart, West Germany, Aug. 25-28, 1981.
42. Noor, A. K., "Survey of Computer Programs for Heat Transfer Analysis," Symposium on Computational Aspects of Heat Transfer in Structures, NASA Langley Research Center, Hampton, VA. Nov. 3-5, 1981.
43. Noor, A. K. and Peters, J. M., "Mixed Models and Reduced/Selective Integration Displacement Models for Vibration Analysis of Shells," International Symposium on Hybrid and Mixed Finite Element Methods, Atlanta, GA, April 8-10, 1981.
44. Noor, A. K. and Peters, J. M., "Multiple-Parameter Reduced Basis Technique for Bifurcation and Postbuckling Analyses of Composite Plates," Ninth U.S. National Congress of Applied Mechanics, Cornell University, Ithaca, NY, June 21-25, 1982.
45. Noor, A. K., "Assessment of Current State-of-the-Art in Modeling Techniques and Analysis Methods for Large Space Structures," Air Force/NASA Workshop on Modeling, Analysis and Optimization of Large Space Structures, Williamsburg, VA, May 13-14, 1982.
46. Noor, A. K. and Peters, J. M., "Recent Advances in Reduction Methods for Instability Analysis of Structures," Symposium on Advances and Trends in Structural and Solid Mechanics, Washington, D.C., Oct. 4-7, 1982.
47. Noor, A. K. and Andersen, C. M., "Finite Element Modeling and Analysis of Tires," NASA Tire Modeling Workshop, NASA Langley Research Center, Hampton, VA, Sept. 7-9, 1982.
48. Noor, A. K. and Peters, J. M., "Instability Analysis of Space Trusses," ASCE Annual

Meeting, New Orleans, LA, Oct. 25-29, 1982.

49. Noor, A. K., Peters, J. M. and Andersen, C. M., "Mixed Models and Reduction Techniques for Large-Rotation Nonlinear Problems," Symposium on Recent Developments in Computing Methods for Nonlinear Solid and Structural Mechanics, Houston, TX, June 20-22, 1983.
50. Noor, A. K., Storaasli, O. O. and Fulton, R. E., "Impact of New Computing Systems on Finite Element Computations," Symposium on Impact of New Computing Systems on Computational Mechanics, ASME Winter Annual Meeting, Boston, MA, Nov. 13-18, 1983.
51. Noor, A. K., "Impact of New Computing Systems on Computational Mechanics," Symposium on Impact of New Computing Systems on Computational Mechanics, ASME Winter Annual Meeting, Boston, MA, Nov. 13-18, 1983.
52. Noor, A. K., "Recent Advances in the Application of Variational Methods to Nonlinear Problems," Seventh Invitational Symposium on the Unification of Finite Elements, Finite Differences and Calculus of Variations, University of Connecticut, Storrs, May 4, 1984.
53. Noor, A. K., "Hybrid Analytical Technique for Nonlinear Analysis of Structures," 25th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Palm Springs, CA, May 14-16, 1984.
54. Noor, A. K., Storaasli, O. O. and Fulton, R. E., "Impact of New Computing Systems on Compuational Mechanics and Flight-Vehicle Structures Technology," AGARD Structures and Materials Panel Meeting, Sienna, Italy, April 2-4, 1984.
55. Noor, A. K. and Tanner, J. A., "Advances and Trends in the Development of Computational Models for Tires," Symposium on Advances and Trends in Structures and Dynamics, Washington, D.C., Oct. 22-25, 1984.
56. Noor, A. K. and Peters, J. M., "Large Deformation Inelastic Dynamic Analysis of Shells of Revolution Via Mixed Finite Element Models," ASME Symposium on Innovative Methods for Nonlinear Problems, New Orleans, LA, Dec. 11, 1984.
57. Noor, A. K. and Peters, J. M., "Penalty Finite Element Models for Nonlinear Dynamic Analysis," 26th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Orlando, FL, April 15-17, 1985.
58. Noor, A. K. and Russell, W. C., "Anisotropic Continuum Models for Beamlike Lattice Trusses," Third Forum on Large Space Structures, Texas A&M University, July 8-10, 1985.
59. Noor, A. K., "Reduction Method for the Nonlinear Analysis of Symmetric Anisotropic Panels," U.S.-Europe Symposium on Finite Element Methods for Nonlinear Problems, Norwegian Institute of Technology, Trondheim, Aug. 12-15, 1985.
60. Noor, A. k., "Global-Local Methodologies and Their Application to Nonlinear Analysis," Workshop on Computational Structural Mechanics and Dynamics, NASA Langley Research Center, Hampton, VA, June 19-21, 1985.
61. Noor, A. K., Andersen, C. M. and Tanner, J. A., "Exploiting Symmetries in the Modeling and Analysis of Tires," Workshop on Computational Structural Mechanics and Dynamics, NASA Langley Research Center, Hampton, VA, June 19-21, 1985.
62. Noor, A. K. and Peters, J. M., "Nonlinear Analysis of Anisotropic Panels," Joint ASCE/ASME Mechanics Conference, Albuquerque, NM, June 24-26, 1985.
63. Noor, A. K. and Peters, J. M., "Mixed Models and Reduction Method for Dynamic Analysis of Anisotropic Shells," ASME Winter Annual Meeting, Miami Beach, FL, Nov. 17-22, 1985.
64. Bostic, S. W. and Fulton, R. E., "A Concurrent Processing Implementation for Structural

Vibration Analysis," 26th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Orlando, FL, April 15-17, 1985.

65. Noor, A. K. and Whitworth, S. L., "Model Size Reduction for the Buckling and Vibration Analyses of Anisotropic Panels," AIAA/ASME/ASCE/AHS 27th Structures, Structural Dynamics and Materials Conference, San Antonio, TX, May 19-21, 1986.

66. Noor, A. K. and Peters, J. M., "Analysis of Laminated Anisotropic Shells of Revolution," Tenth U.S. National Congress of Applied Mechanics, University of Texas at Austin, June 16-20, 1986.

67. Noor, A. K. and Peters, J. M., "Error Indicators and Accuracy Improvement of Finite Element Solutions," International Conference on Reliability of Methods for Engineering Analysis, University College of Swansea, United Kingdom, July 9-11, 1986.

68. Noor, A. K., "Advances and Trends in Computational Structural Mechanics,' Symposium on Future Directions of Computational Mechanics, ASME Winter Annual Meeting, Anaheim, CA, Dec. 10-11, 1986.

69. Noor, A. K., "Flight-Vehicle Structures Education in the United States - Assessment and Recommendations," 28th AIAA/ASME/AHS/ASEE Structures, Structural Dynamics and Materials Conference, Monterey, CA, April 6-8, 1987.

70. Noor, A. K. and Tanner, J. A., "Advances in Contact Algorithms and Their Application to Tires," American Chemical Society Meeting, Montreal, Canada, May 26-29, 1987.

APPENDIX II - THESES AND DISSERTATIONS

1. Lowder, H. E., "Approximate Techniques for Structural Reanalysis," Oct. 1974.

2. Berger, P. E. "Investigation of the Effects of Structural Dynamics on Design for Fatigue Life," May 1975.

3. Camin, R. A., "Nonlinear Finite Element Analysis of Composite Cylinder Shells," Oct. 1975.

4. Mathers, M. D., "Finite Element Analysis of Laminated Composite Plates and Shells," D.Sc. dissertation, Feb. 1976.

5. Farley, G. L., "Interactive Structural Optimization with Strength and Flutter Constraints," April 1976.

6. Greene, W. H., "Continuum Models for Static and Dynamic Analysis of Repetitive Trusses," Oct. 1977.

7. Peebles, J. H., "Optimal Control of a Helicopter Rotor in Hover," Nov. 1977.

8. Nemeth, M. P., "Continuum Models for Repetitive Lattice Structures with Rigid Joints," Sept. 1979.

9. Camarda, C. J., "Experimental Investigation of Graphite/Polyimide Sandwich Panels in Edgewise Compression, Summer 1980.

10. Weisstein, L. S., "Continuum Models for Repetitive Beamlike Lattice Structures," Feb. 1982.

11. Balch, C. D., "Hybrid Techniques for Nonlinear Steady-State Thermal Analysis," Jan. 1983.

12. Dompka, R. V., "Improved Analytic Simulation of Impact Dynamics," Feb. 1984.

13. Knight, N. F., Jr., "A Modified Modal Method for Nonlinear Dynamic Analysis of Structures," D.Sc. dissertation, May 1984.

14. Harmon, D. M., "A Hybrid Analytical Technique for the Nonlinear and Postbuckling Analysis of Composite Panels," Feb. 1985.

15. Belvin, W. K., "Modeling of Joints for the Dynamic Analysis of Truss Structures," Dec. 1985.

16. Rouse, M., "Postbuckling of Flat Unstiffened Graphite-Epoxy Plates Loaded in Shear," Oct. 1985.

17. Betzen, V. R., "Mixed Models and Reduction Techniques for Impact Dynamics," Dec. 1985.

18. Russell, W. C., "Continuum Modeling Theories for Repetitive Lattice Space Structures," Oct. 1985.

19. Fetterman, T. L., "Free Vibration Sensitivity Derivative Calculations Via Reduction Methods," Feb. 1987.

20. Swats, C. F., "The Effect of Circular Through Holes on the Inelastic Buckling of Thick Wall Cylinders Under Axial Compression," May 1987.

21. Jeffrey, G. L., "Postbuckling Analysis of Laminated Anisotropic Panels," Aug. 1987.

22. Jegley, D. C., "An Analytical Study of the Effects of Transverse Shear Deformation and Anisotropy on the Buckling of Laminated Cylinders," Aug. 1987

APPENDIX III - LIST OF WORKSHOPS AND SYMPOSIA

1. Symposium on Future Trends in Computerized Structural Analysis and Synthesis, Oct. 30-Nov. 1, 1978, Washington, D.C.

2. Symposium on Mathematical Modeling in Structural Engineering, Oct. 24-26, 1979, NASA Langley Research Center, Hampton, VA.

3. Symposium on Computational Methods in Nonlinear Structural and Solid Mechanics, Oct. 6-8, 1980, Washington, D.C.

4. Symposium on Computational Aspects of Heat Transfer in Structures, Nov. 3-5, 1981, NASA Langley Research Center, Hampton, VA.

5. Symposium on Advances and Trends in Structural and Solid Mechanics, Oct. 4-7, 1982, Washington, D.C.

6. Workshop on Failure Analysis and Mechanisms of Failure of Fibrous Composite Structures, March 23-25, 1982, NASA Langley Research Center, Hampton, VA.

7. Symposium on Impact of New Computing Systems on Computational Mechanics, ASME Winter Annual Meeting, Nov. 13-18, 1983, Boston, MA.

8. Symposium on Advances and Trends in Structures and Dynamics, Oct. 22-25, 1984, Washington, D.C.

9. Workshop on Computational Structural Mechanics and Dynamics, June 19-21, 1985, NASA Langley Research Center, Hampton, VA.

10. Symposium on Future Directions of Computational Mechanics, ASME Winter Annual Meeting, Dec. 10-11, 1986, Anaheim, CA.

APPENDIX IV - LIST OF GRADUATE RESEARCH ASSISTANTS SUPPORTED BY THE GRANT 1972-1986

1. Lowder, Harold E., B.S. (Aerospace Engineering), Purdue University (Sept. 1972-Sept. 30, 1974)

2. Berger. Paul E., B.S. (Aerospace Engineering), University of Kansas (Sept. 1972-Oct. 31, 1974)

3. Mathers, Michael D., M.S. (Applied Mechanics), University of California at San Diego (Sept. 1972-Dec. 31, 1975)

4. Camin, Robert A., B.S. (Aerospace Engineering), Virginia Polytechnic Institute (Sept. 1973-Oct. 17, 1975)

5. Farley, Gary L., B.S. (Aerospace Engineering), Virginia Polytechnic Institute (Sept. 1973-Aug. 31, 1975)

6. Rehak, Daniel R., B.S. (Civil Engineering), Carnegie-Mellon University (Sept. 1974-May 1. 1975)

7. Greene, William H., B.S. (Mechanical Engineering), Georgia Institute of Technology (June 1975-Sept. 30, 1977)

8. Peebles, James H., B.S. (Aerospace Engineering), Univ. of Illinois at Urbana-Champaign (Sept. 1, 1975-Nov. 1, 1977)

9. Walton, B., B.S. (Civil Engineering), University of Kentucky (Sept. 1, 1975-Oct. 1, 1975)

10. Lee, David W., B.S. (Aerospace Engineering), New York University (June 15, 1976-Aug. 20, 1976)

11. Nemeth, Michael P. (Civil Engineering), North Carolina State University (June 16, 1977-Aug. 31, 1979)

12. Knight, Norman F., M.S. (Engineering Mechanics), Virginia Polytechnic Institute and State University (August 29, 1977-July 31, 1980)

13. Weisstein, Larry S., B.S. (Aerospace Engineering), California State Polytechnic Univ. at Pomona (July 2. 1979-Sept. 30. 1981)

14. Bush, Daniel J., B.S. (Mehanical Engineering), University of Colorado at Boulder (January 4, 1980-July 8, 1982)

15. Balch, Chad D., B.A. (Physics), Harvard University
(July 9, 1980-Jan. 21, 1983)

16. Forbes, Allen K., B.S. (Geological Engineering), University of Nevada at Reno
(August 1, 1980-Nov. 26, 1980)

17. Dompka, Robert V., B.S. (Civil Engineering), Duke University
(Sept. 1, 1981-Jan. 11, 1984)

18. Peterman, Louis W., Jr., M.S. (Mechanical Engineering), Michigan Technological Univ.
(Sept. 1, 1981-April 30, 1982)

19. Cooper, Michael J., M.S. (Engineering Science), State University of New York at Buffalo
(Sept. 1, 1981-Aug. 12, 1983)

20. Harmon, David M., B.S. (Mechanical Engineering), University of Rochester
(Aug. 23, 1982-Feb. 14, 1985)

21. Russell, William C., B.S. (Aeronautical and Astronautical Engineering), Ohio State Univ.
(July 5, 1983-Oct. 25, 1985)

22. McLeod, N. Douglas, B.S. (Aerospace Engineering), Georgia Institute of Technology
(July 25, 1983-Dec. 13, 1983)

23. Betzen, Vincent R., B.S. (Mechanical Engineering), Wichita State University
(August 29, 1983-Dec. 24, 1985)

24. Luders, Mark A., B.S. (Mechanical Engineering), University of Washington
(August 31, 1983-Dec. 19, 1983)

25. Forde, J. Scott, B.S. (Mechanical Engineering), South Dakota State University
(January 4, 1984-Sept. 14, 1984)

26. Jeffrey, Glenda L., B.S. (Mechanical Engineering), Purdue University at Indianapolis
(August 23, 1984-Sept. 26, 1986)

27. McCleary, Susan L., B.S. (Aeronautical and Astronautical Engineering), Ohio State Univ.
(August 20, 1984-Oct. 4, 1985)

28. Fetterman, Timothy L., B.S. (Aerospace Engineering), University of Florida
(August 30, 1984-Feb. 28, 1987)

APPENDIX V - LIST OF EQUIPMENT PURCHASED

No. of Items	Description	Cost	Date Purchased
4	IBM PC Model No. 14 No. 5150 Standard	$5,219.20	2/17/83
1	IBM-XT Model 87 No. 5160	3,964.00	
4	80 CPS Matrix Printer w/graphics no. 5152-002	1,666.00	
5	Printer Cable no. 1525612	192.50	
5	IBM PC DOS No. 6024001	150.00	
1	Fortran Compiler No. 6024012	262.00	
1	Monochrome Display & Printer Adapter No. 1504900	234.50	
1	Monochrome Display No. 5151001	241.50	
1	NEC 3350 Ltr Quality Printer	$1,840.00	2/17/83
1	NEC 3550 Cut Sheet Guide	107.00	
2	Thimble, light italic/manifold #803-682A	49.40	
2	Thimle. prestige elite/prestige renown #803-392A	49.40	
1	Black Mylar Multi-strike Ribbon	11.40	
1	Black Fabric Ribbon	9.20	
4	Princeton Color Monitor	$2,600.00	2/22/83
4	Plantronics Graphics Adapter & Software	2,600.00	
4	Quadboard (192KB memory, clock serial port, parallel port)	2,380.00	
4	Microware Fastpak 4087 with 87 Fortran	375.00	
1	Easywriter II from IUS	275.00	
1	Easyspeller from IUS	125.00	
8	320K Disk Drive	$2,262.40	4/18/83
1	Grafmatic MS Fortran 3.1 vers.	$ 97.40	
1	Citoh Printer	$ 368.46	3/7/84
4	256K Ram Card	$1,370.00	3/13/84
18	64K "Upgrade Kits"	$ 901.97	3/14/84
1	DPATH Utility for PC-DOS 2.0+	$ 25.00	8/11/84
1	Polylibrarian 1	$ 100.50	8/17/84
1	Polymake	100.50	8/17/84

6	64K RAM Upgrades	$ 269.46	9/24/84
1	Princeton Graphics HX-12 Color Monitor	469.00	
1	AST Six-Pak Plus w/64K	269.00	
1	Epson FX-80 Printer	429.00	
1	Epson FX-80 Tractor	25.00	
1	Tecmar Graphics Master	485.00	
1	IBM Parallel Cable	20.00	
3	8087 Chips	525.00	
2	Cable Monitor Power Cord Plug	$ 24.00	6/1/85
2	FDD Adaptor Cable	$ 42.40	6/25/85
2	6' IBM Parallel Printer Cable	$ 42.40	7/9/85
2	20 Meg Internal HD System Microscience	$ 1,358.00	8/10/85
2	Ast Sixpkplus w/384K	498.00	
10	64K Ramset 200 nS	100.00	
2	Intel 8087 Math Chip	198.00	
	Total	$32,331.59	

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